ATMOSPHERIC EFFECTS ON SONIC-BOOM SIGNATURES

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Station, Hampton, Va., U.S.A.

Presented at the Fifth International Congress
on Acoustics (ICAS)

Liege, Belgium
September 7-14, 1965

[redacted]

NX# 56436

5e CONGRÈS INTERNATIONAL D'ACOUSTIQUE
LIÈGE 7-14 SEPTEMBRE 1965

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ABSTRACT

Data from flight experiments illustrate the nature of various atmospheric effects on sonic-boom ground-pressure signatures. Atmospheric refraction, grazing incidence wave impingement, and turbulence interaction phenomena are discussed along with their significance regarding the community response problem of sonic booms.

INTRODUCTION

The manner in which sonic booms affect community acceptance of such aircraft as the supersonic transport requires a knowledge of the effects of aircraft operation and the atmosphere on the ground exposures. Shown schematically in figure 1 is an airplane flight track extending from subsonic to supersonic speeds. Beneath the flight track are shown sketches of the shock-wave impingement patterns and the associated distributions of N-wave type pressures, both along the track and perpendicular to it. The information of the paper is in the form of a report on the state of knowledge of sonic-boom phenomena, dealing first with the pressure buildups in the transonic speed range (refs. 1 and 2) and with the lateral extent of the pattern in steady flight for quiescent atmospheric conditions (refs. 3 and 4). Also, there will then be a discussion of recent data from flight-test studies relating to atmospheric dynamic effects on the sonic-boom signatures (ref. 5), and finally brief discussions of the significance of signature shape on the response of people and structures (ref. 6).

EFFECTS OF ACCELERATED FLIGHT

An extensive series of ground-pressure measurements has been made for longitudinal aircraft accelerations from 0.9 to about 1.5 Mach number at a constant altitude of 37,200 feet with a special array of microphones extending about 23 miles along the ground track. The measured data points from three such acceleration flights are shown at the bottom of figure 2. The data at the zero position represent the so-called superboom condition where pressure buildups occur. The data for the three separate flights were normalized by plotting the highest measured overpressure values at this zero position. The direction of the aircraft is from left to right, as indicated by the sketches at the top along with corresponding tracings of measured signatures. The data points of the figure represent peak overpressures as defined in the sketch. The low-value points to the left of the figure represent noise and are observed as rumbles. The high-value points near the center of the figure correspond to measurements that are very close to the so-called focus point, and thus represent what are conventionally described as superbooms. To the right of the focus point are two distinct sets of measurements which relate to the region of multiple booms. For convenience in illustrating the trends of the data, a solid

*Material of this paper abstracted from paper presented at NASA Conference on Aircraft Operating Problems, Langley Research Center, Hampton, Va., May 10-12, 1965.

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and dashed line are faired through the data points. The data points which cluster about the solid curve relate to the first signature to arrive in all cases, and this eventually develops into the steady-state signature. The data points that cluster about the dashed curve relate, in all cases, to the second signature to arrive. These values are seen to generally decrease as distance increases, and eventually this second wave ceases to exist because of the refraction effects of the atmosphere.

The highest overpressures are measured in a very localized region. These values are noted to be as high as 2.5 times the maximum value observed in the multiple-boom region and are thus in general agreement with the measured results for lower altitude tests of reference 1. It is further noted that the main multiple-boom overpressure values are of the same order of magnitude as those predicted for comparable steady-state flight conditions. Available overpressure prediction methods give good agreement in the multiple-boom region but are not considered reliable in the superboom region.

The locations of the superboom and multiple-boom regions are predictable within ±5 miles, provided such information as flight path, altitude, and acceleration rate of the aircraft is available.

LATERAL-SPREAD PATTERNS

With regard to the steady-flight conditions, some recent experiments have also been conducted in an effort to define more exactly the pressure distribution near the extremity of the shock-wave pattern on the ground. Some sample data are shown in figure 3. Particular emphasis was placed on the region where a grazing condition exists due to atmospheric refraction, as suggested by the ray-path sketch at the top of the figure. Flights were made at altitudes of 52,200 and 37,200 feet and Mach numbers of 2.0 and 1.5, respectively, during quiescent atmospheric conditions, and the results are compared with theory in the data plots at the bottom. The results from the flight at 52,200 feet altitude and Mach number 2.0 show that the pressures are generally highest on the track and decrease generally as distance increases (solid symbols represent no measured disturbance). The fact that measurements were obtained beyond the theoretically predicted cutoff distance by the method of reference 4 led to more definitive studies at 37,200 feet altitude and at Mach number 1.5. These data, which were obtained from four flights involving various displacement distances of the aircraft from the overhead position, are similar and, in fact, indicate measured signals as much as 15 miles beyond the predicted cutoff distance.

A better understanding of this phenomenon may be obtained from examination of some sample waveforms based on measurements at various distances. It can be seen that sharply defined shock-wave type signatures exist generally for the region predicted by the calculations. At distances beyond the predicted cutoff, the signatures lose their identity and associated observations indicate the existence of rumbles, as described previously.

OTHER EFFECTS OF THE ATMOSPHERE

Measurements of sonic-boom signatures have been made at specific measuring points for a large number of supersonic flights, and some sample results are shown in figure 4. At the left of the figure are shown fighter aircraft sonic-boom signatures (ref. 5). It can be seen that these vary widely from sharply peaked waves at the top to rounded-off waves of sinusoidal appearance at the bottom. The signatures on the right-hand side of the figure have been recently obtained for bomber aircraft and have a noticeably longer wavelength or time duration (about 0.18 sec). It can be seen that the main distortions of the waves in each case are associated with the rapid compression phases and that these distortions are of the same general nature for waves of short and long wavelengths. The results of figure 4 are in qualitative agreement with similar data for a given flight but for measurements at a number of stations (see ref. 5).

Because of the large number of data points available for a range of flight conditions, it was possible to make statistical analyses of the variations of overpressure amplitude. Samples of the overpressure variation data are given in figure 5 as relative cumulative frequency distributions and histograms showing probability of occurrence. In the left-hand plot of the figure are shown amplitude distributions for a fighter aircraft, and in the right-hand plot are similar data for a bomber aircraft. The probability of equaling or exceeding a given overpressure-ratio value is plotted on the vertical scale as a function of the ratio of the measured overpressure values divided by the maximum predicted value for the respective flight conditions (which occur on the ground track). For this type of presentation, the data points would all fall on a straight line if the logarithms of the data fitted a normal distribution. For the fighter aircraft, data were obtained on the ground track and at distances up to 10 miles from it. From an inspection of these curves, it can be seen that a wider variation in the amplitudes occurred for the more remote stations. It was also noted that the probability of encountering high values of pressure was somewhat greater for the lateral stations. In the case of the bomber aircraft, fewer data points were available for analysis and hence the statistical sample is not as reliable. Based on the data available, the variation in amplitude for the bomber data, which have markedly longer wavelengths, is noted to be only slightly less than that for the fighter aircraft. It is significant to note that some of the pressure buildups due to atmospheric effects are of the same order of magnitude as those associated with the superboom phenomenon (fig. 2).

RESPONSE PHENOMENA

The nature of the acoustic inputs for two types of exposure situations is summarized in figure 6. The top trace represents the outside-exposure situation, whereas the bottom two traces represent the inside-exposure situation. In general, the ear is sensitive to the rapid changes in pressure associated with the two compressions and is not sensitive to the slowly varying pressure in between. Studies at the University of Southampton which relate directly to the outside situation have shown that the overpressure values and the initial rise time were both important with regard to loudness judgments. Of these, the rise-time factor was dominant.

A microphone inside of a room records a pressure variation in that room similar to that of the middle trace. This has the gross features of a damped sine wave, the frequencies of which correspond to the fundamental vibration-mode frequencies of the main framing members of the building. Although this inside pressure variation is of large amplitude, it usually occurs at a characteristic frequency at which the human ear is not very sensitive. In order to better define the audible acoustic input to an inside observer, simultaneous measurements were made with a microphone system having a response similar to that of the human ear. The objective here was to eliminate the dominant low-frequency components that the ear does not normally respond to in order to better define the high-frequency components for which the ear is much more sensitive. Such available acoustic signals are believed to be associated with the vibration of small building components and miscellaneous items of furnishings and equipment. The exposure for the inside observer is strongly shaped by the response of the building. The results of studies to date (ref. 6) have suggested strongly that building vibrations play a dominant role in shaping the judgments of community observers in sonic-boom exposure situations.

The significant factors in the response of structures to sonic-boom signatures are illustrated in figure 7. Represented by the sketches at the top of the figure are such features of the input as the overpressure, impulse, and the period. In the case of the structure, the most significant feature is the period of its first natural vibration mode as indicated by the sketch on the right. Analytical studies have suggested that the ratio of the period of the input to the natural vibration period of the structure determines the manner in which the structure responds. The plot at the bottom of the figure represents a brief summary of the situation for various combinations of the period of the input and the natural period of the structure; for instance, for a short-period input, as in the case of a fighter aircraft, and a long-period response, such as for a large structure, the impulse is believed to be the significant feature of the input. On the other hand, for the case of a long-period input or for a large airplane and a short period of the structure as in the case of the components of a building, the overpressure is believed to be the significant feature of the input. Many of the structures which are of concern in a community are of such a nature that they do not clearly fall into either of the two categories of the figure, and hence it must be concluded that both the overpressure and impulse are significant.

CONCLUDING REMARKS

The acceleration and lateral-spread phenomena appear to be fairly well understood and predictable for current and future aircraft. Variations in the sonic-boom signature as a result of the effects of the atmosphere can be expected during routine operations. From the data evaluated to date, very similar variations in pressure signatures are noted for a range of sonic-boom wavelengths. It is in the area of community acceptance of sonic booms that the greatest questions still exist. A more definite answer to the community-acceptance problem will have to await adequate flight experience with larger aircraft.

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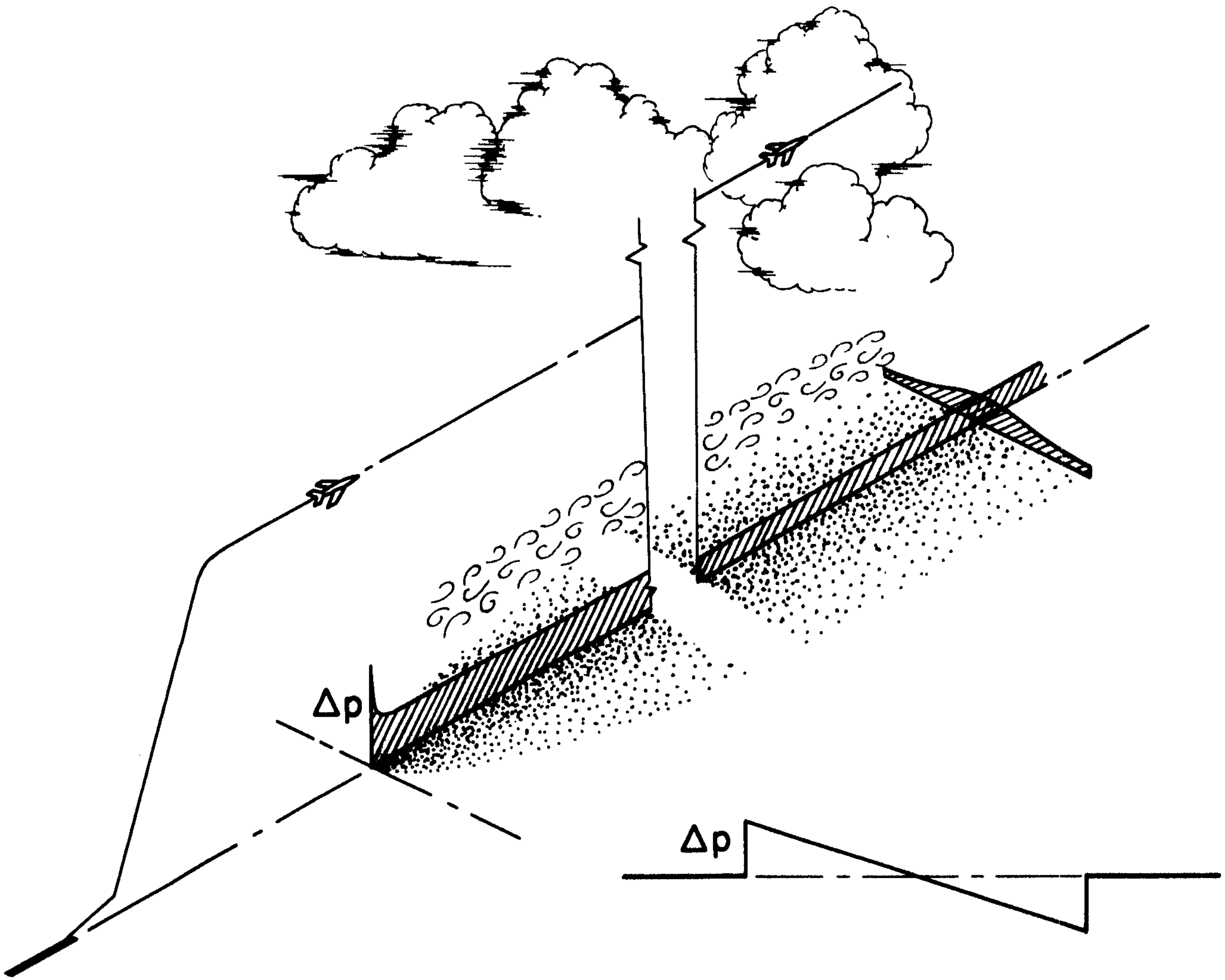

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Figure 1.- Schematic diagram of the sonic-boom ground-exposure patterns for an aircraft during accelerated and steady flight.

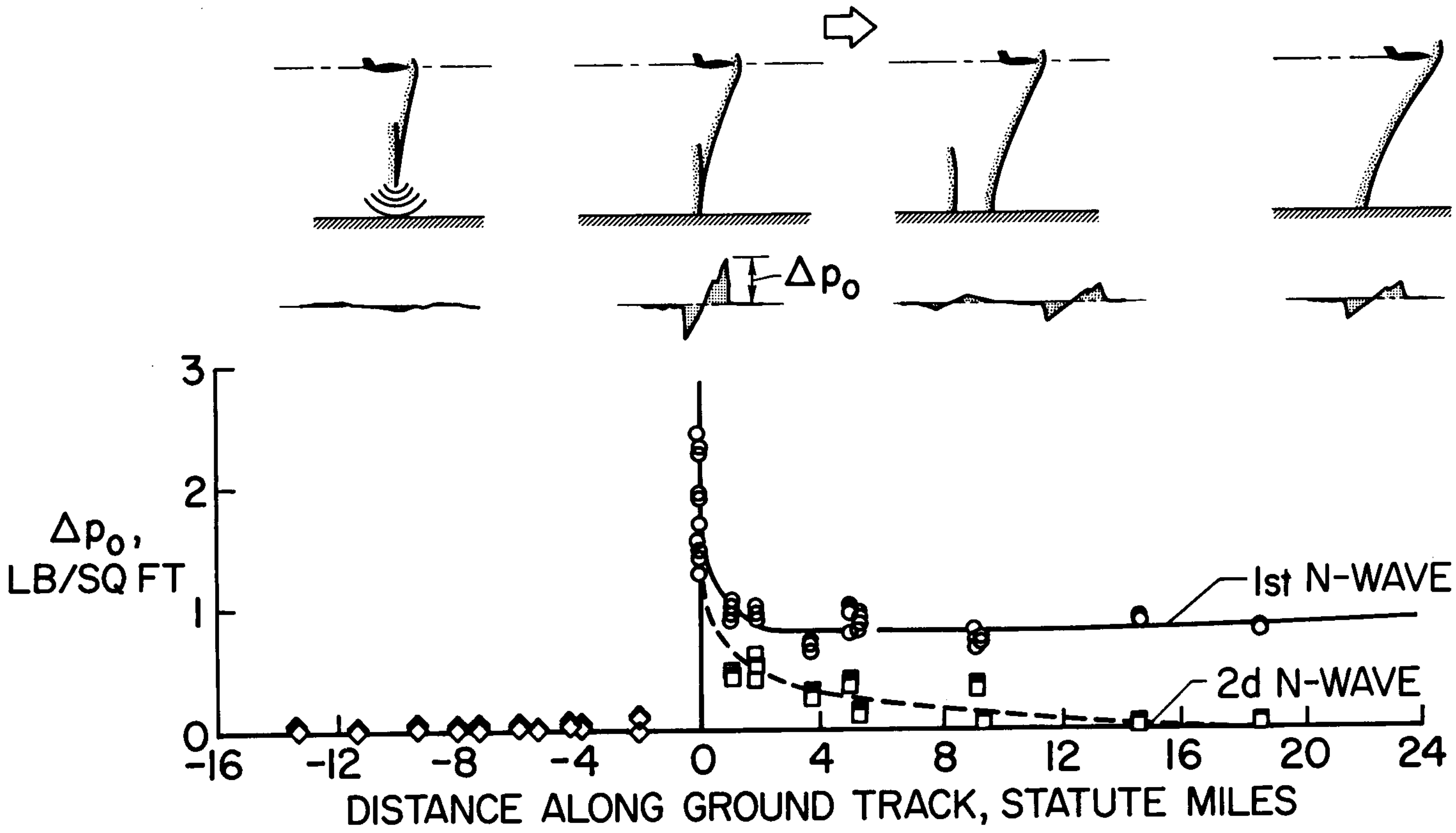

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Figure 2.- Measured sonic-boom overpressures at various locations along the ground track of a fighter aircraft for longitudinal accelerations from about 0.9 to 1.5 Mach number at a constant altitude of 37,200 feet.

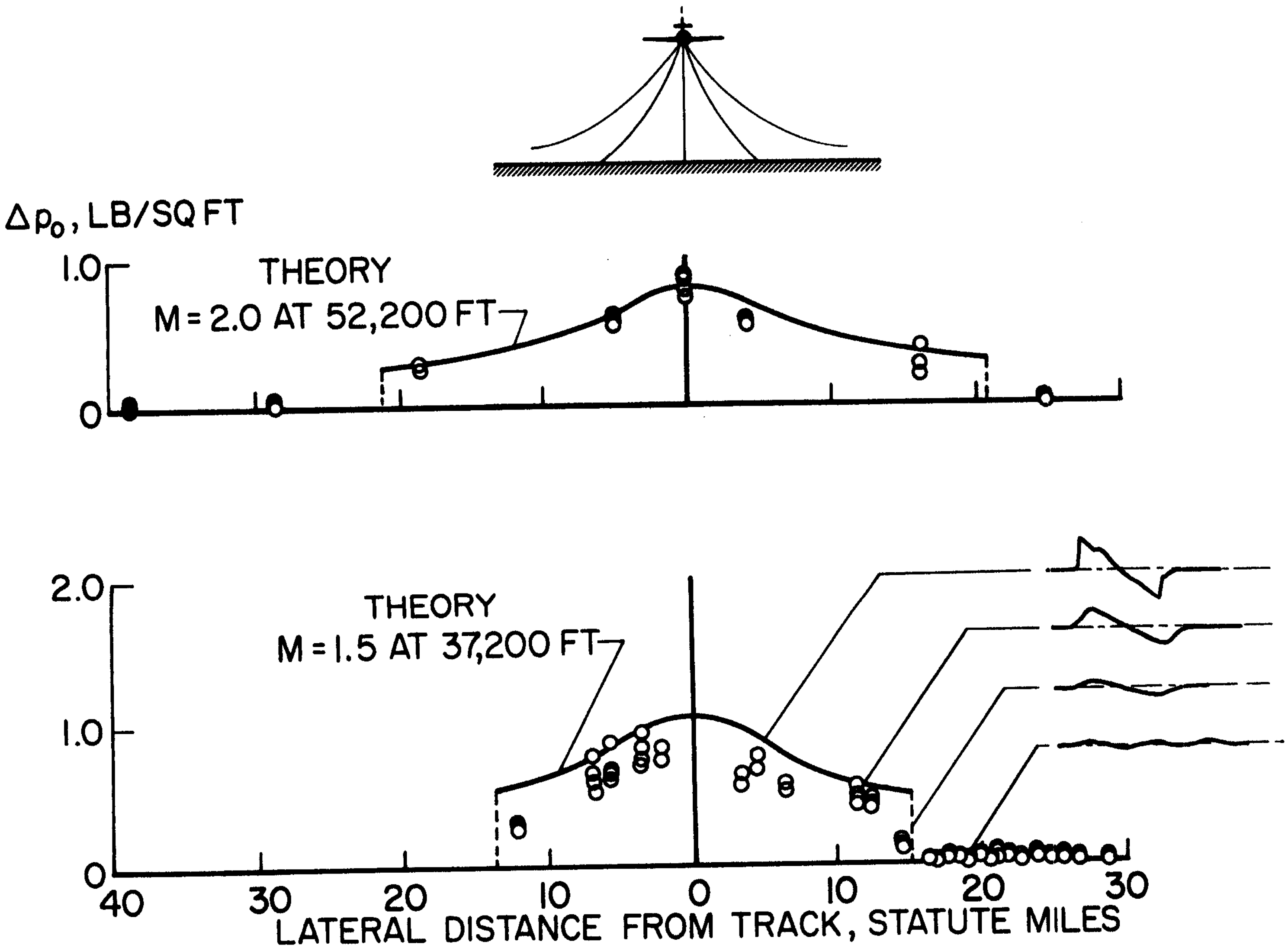

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Figure 3.- Measured sonic-boom overpressures at ground level as a function of lateral distance for fighter aircraft in steady-level flight.

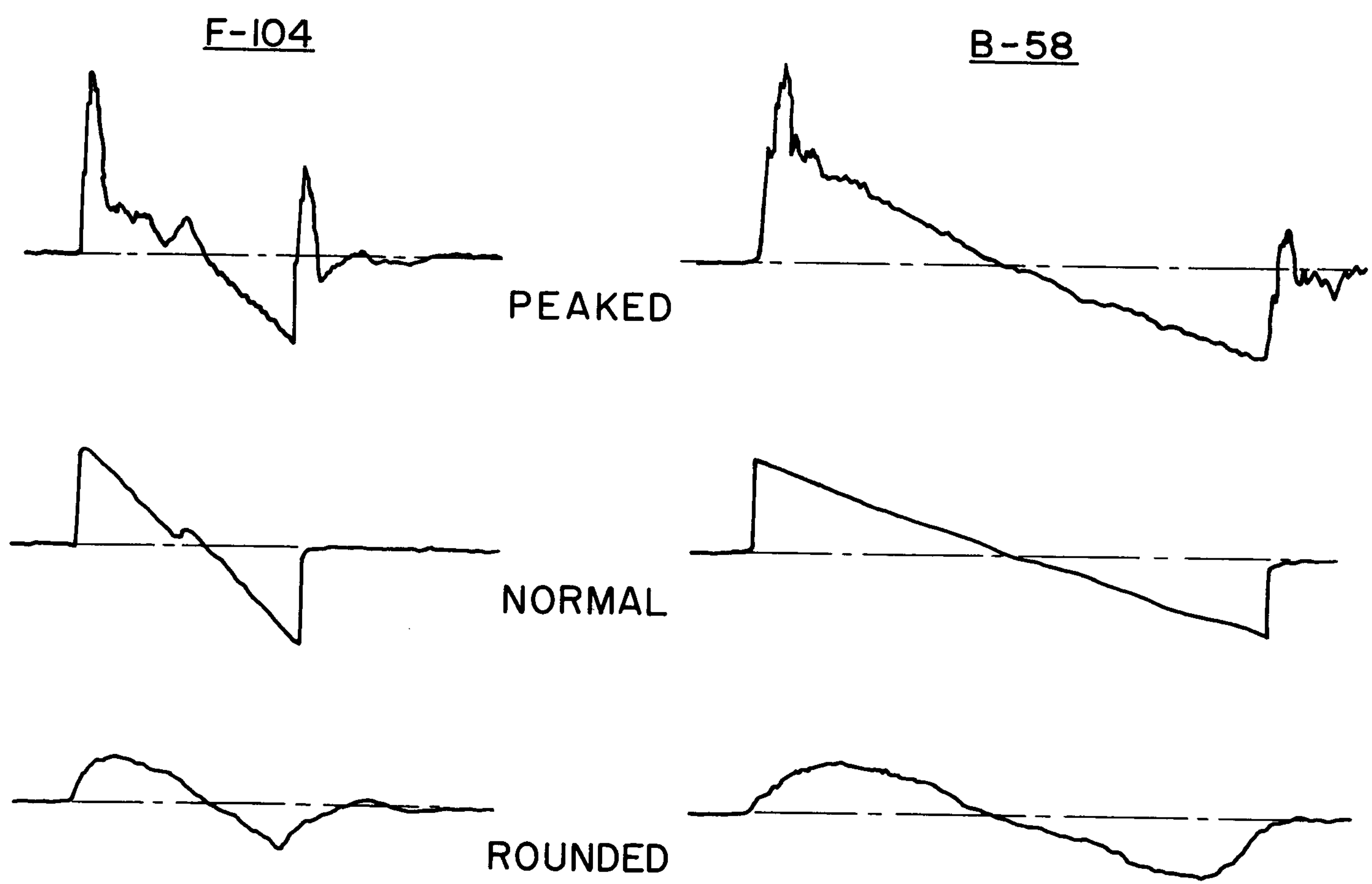

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Figure 4.- Variation of measured sonic-boom pressure signatures at ground level for both fighter and bomber aircraft (in steady-level flight) due to effects of the atmosphere.

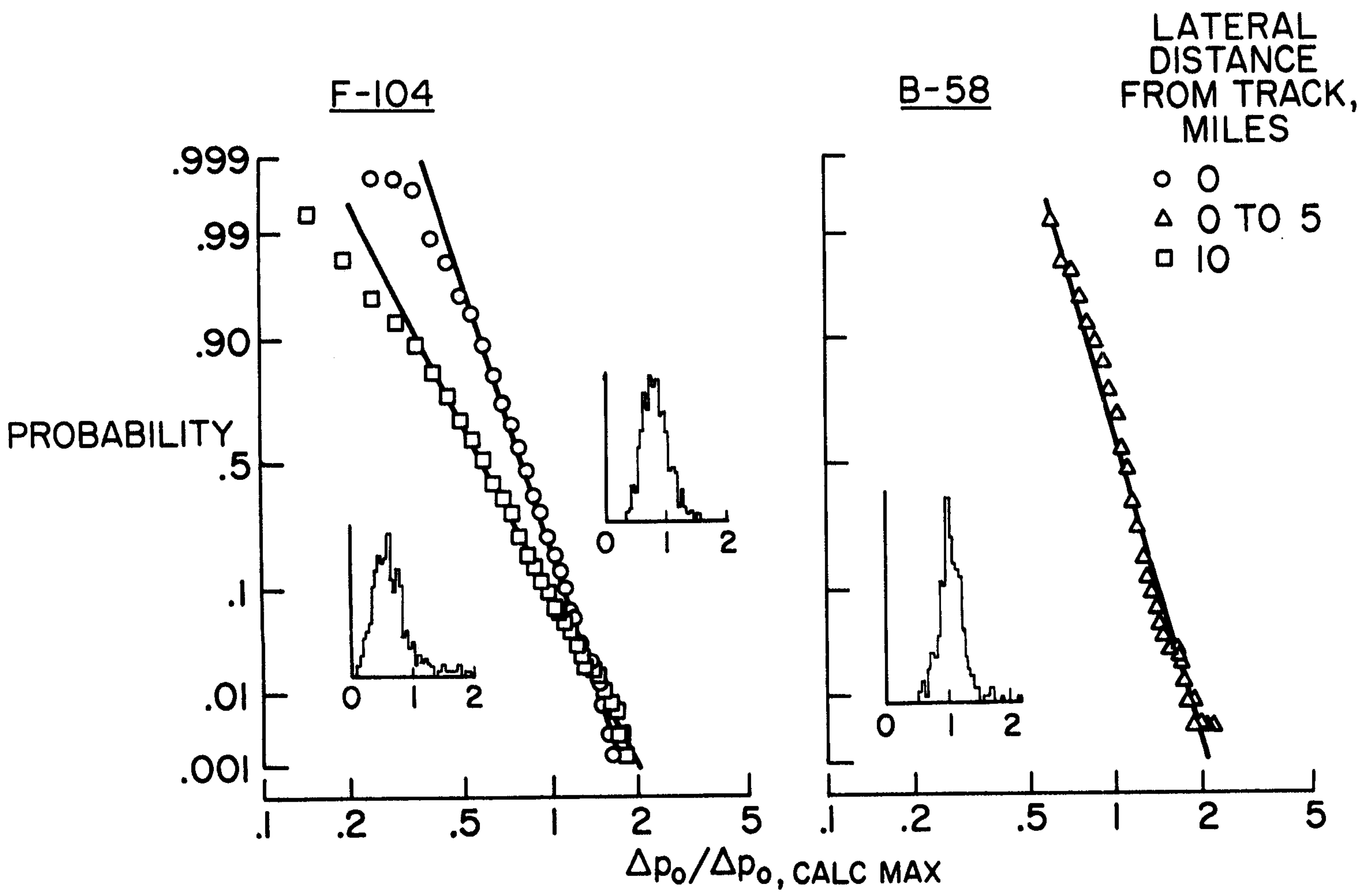

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Figure 5.- Probability of equaling or exceeding a given value of the ratio of measured to calculated maximum overpressures for fighter and bomber aircraft and for a range of steady-level flight conditions.

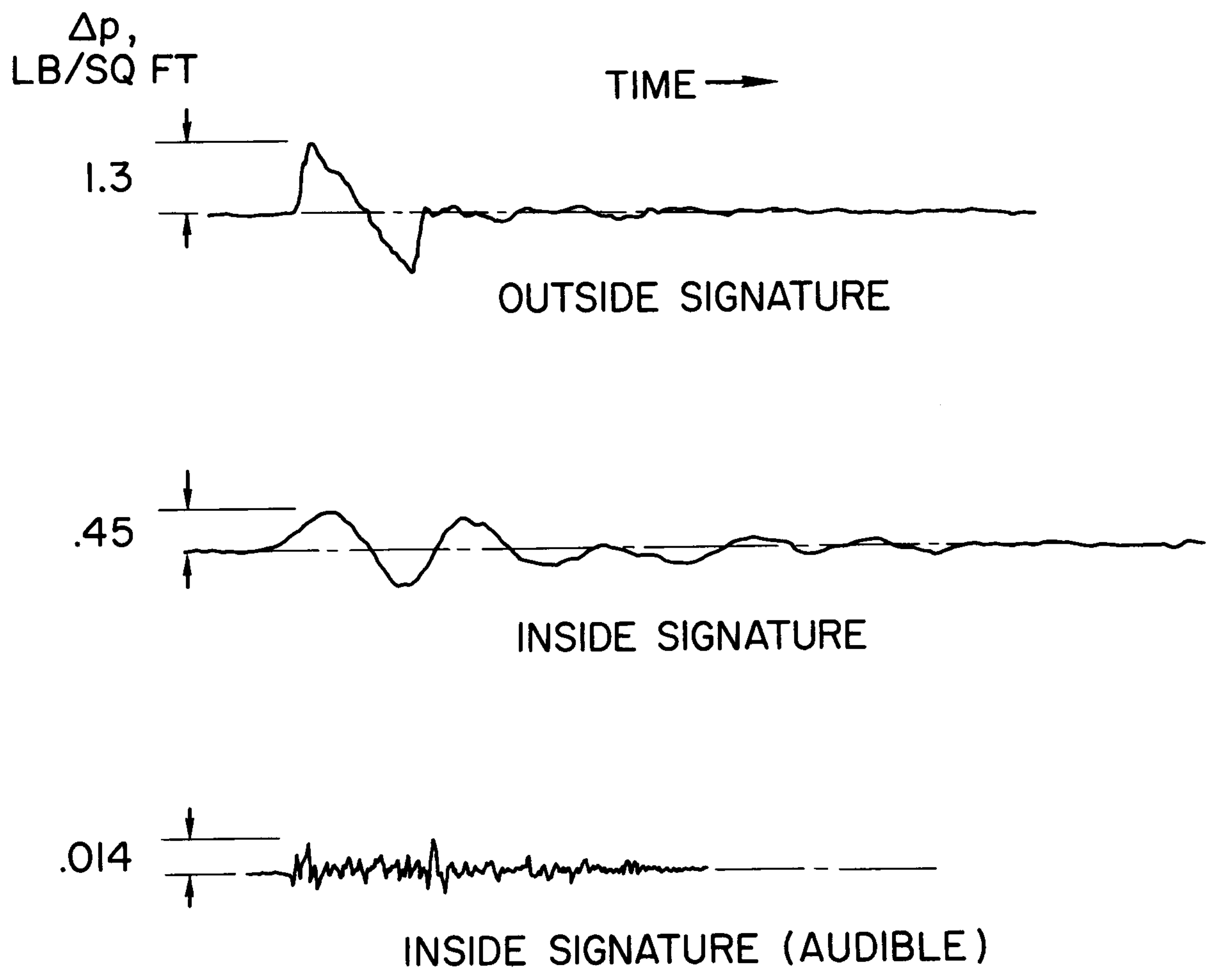

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Figure 6.- Sample sonic-boom pressure-time histories for both outside and inside microphone locations resulting from fighter aircraft in steady flight.

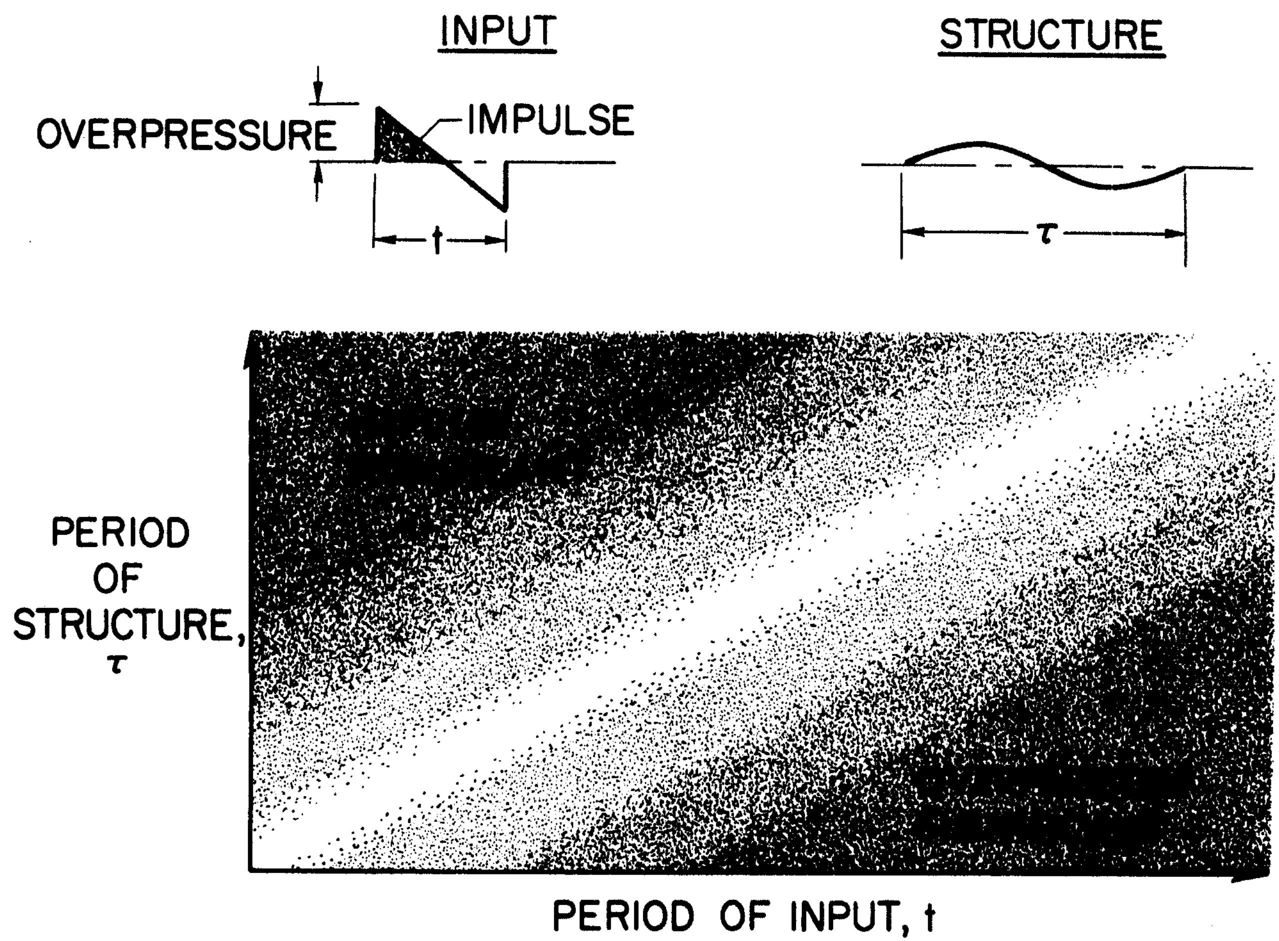

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Figure 7.- Factors in the response of structures to sonic-boom signatures.

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